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IMMERSION AGENT, COUPLING DEVICE AND METHOD FOR COUPLING AN OPTICAL WAVEGUIDE

[Immersionsmittel, Kopplungsanordnung und Kopplungsverfahren für Lichtwellenleiter]

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The invention relates to an immersion agent, a coupling device, and also a method for coupling at least one optical waveguide (LWL) to an optical component (chip) or for connecting an LWL to an optical component.

An optical coupling device is used for coupling or bridging light between two optical waveguide end faces, for example, between the end face of an LWL fiber made from a core and cladding and the opposing end face of a waveguide structure provided on a chip. Such coupling devices are used, for example, in optical filters that operate according to the phased-array principle. These have a coupling face in which light enters at a certain position, wherein the output wavelength of the optical fiber depends on the geometric position of the coupling position. Optical fibers operating according to the phased-array principle are used, in particular, as multiplexers or demultiplexers in the field of optical communications transmission, because they exhibit low insertion attenuation and high crosstalk suppression.

The German Patent Application DE 44 22 651.9 describes a so-called phased-array filter whose center wavelength is fixed by positioning the LWL fiber coupling the light into the chip wavelength structure and thus can be adjusted precisely. This happens through displacement of the waveguide end faces relative to each other.

It was already proposed to change the position of the end face of the LWL relative to the coupling face of the chip in such a way that a length-variable element carries the fiber and therefore this fiber is /2*
shifted parallel to the direction of elongation of the length-variable element.

In order to realize an optical coupling between an LWL, an LWL ribbon or fiber array and an optical component containing active and/or passive elements, the LWL must be held in a defined position relative to the coupling face of the chip and must be connected to the corresponding waveguide

* [Numbers in right margin indicate pagination of the original text.]

structure. This is realized conventionally through direct adhesion of the fiber ends to the chip. In the cases named above, however, a direct adhesion or fusing of the fiber ends to the chip is not desired, because this would prevent the necessary relative movement between the fiber and the chip. In order to improve the insertion attenuation and to reduce the power fluctuations, previously an immersion agent was introduced between the fiber and the chip. As the immersion agent, in particular, a durable gel, for example, an additive, cross-linked silicone rubber has been used. The silicone rubber is made from two components whose mixture ratio is 1:1, so that the rubber completely hardens after being introduced. The hardening is considered necessary to prevent the immersion from flowing away.

Because an enclosed volume is formed between the fiber and its fiber holder on one side and the chip on the other side, cracks or vacuoles (vacuum bubbles) that significantly increase the insertion attenuation of the component are created in the immersion gel due to shrinkage during the cooling process. In addition, the crack formation is also assisted by the relative movement mentioned above between the fiber and the chip.

Therefore, the invention is based on the task of providing an optical coupling having low insertion attenuation between an optical waveguide, for example, a fiber or a fiber array, and an optical /3
component/chip.

To achieve this task, an immersion agent for coupling optical waveguides to an optical chip is characterized in that a transparent elastomer is used as the immersion agent, wherein the elongation at tear of the elastomer is greater than 300% and its elastic modulus has a value smaller than 200 N/cm^2. The immersion is therefore set to be soft enough that when cooling, sufficient gel flows out from the edge regions of the immersion and no stress leading to cracks and vacuoles can build up. On the other hand, the immersion material is not so fluid that it can flow out of the volume between the optical

waveguide and the chip, so that it is guaranteed that the immersion material remains in this intermediate space during the entire service life of the component.

One advantageous construction of the immersion agent according to the invention is characterized in that the matrix of the immersion agent contains a non-cross-linked percentage of liquid phase. Through corresponding setting of the mixture ratio, for example, of a two-component immersion agent, the immersion agent can be adjusted to be soft in the desired way.

Another advantageous construction of the immersion agent according to the invention is characterized in that the immersion agent contains a liquid phase percentage of 1-10% of an immersion liquid with low vapor pressure. The addition of a liquid phase percentage is a simple alternative to generating an immersion agent with the properties mentioned above.

Another advantageous construction of the immersion agent according to the invention is /4
characterized in that an immersion oil or a softener selected as a function of the elastomers is used as the immersion liquid, wherein the immersion agent is adjustable in a simple way through the addition of the immersion oil.

Another advantageous construction of the immersion agent according to the invention is characterized in that the immersion agent is silicone rubber and that the immersion liquid is a silicone softener, in particular, silicone oil. Because the silicone rubber has pronounced adhesiveness also in the not completely cross-linked state, stability of the coupling of the component over its entire service life is guaranteed.

Another advantageous construction of the immersion agent according to the invention is characterized in that the immersion agent is epoxy acrylate and that the immersion liquid is an epoxy acrylate softener, in particular, polyisobutylene.

Another advantageous construction of the immersion agent according to the invention is characterized in that the immersion agent is urethane acrylate and that the immersion liquid is a urethane acrylate softener, in particular, polyisobutylene.

The two just mentioned immersion agents involve so-called radiation cross-linking elastomers that represent an advantageous alternative to silicone rubber. Also, this immersion agent can have the properties required by the immersion agent according to the invention.

Another advantageous construction of the immersion agent according to the invention is /5
characterized in that the immersion liquid or the softener is an aliphatic or aromatic oil, so that a series of softeners is available, wherein the special softener can be selected according to the appropriate initial conditions.

Another advantageous construction of the immersion agent according to the invention is characterized in that the silicone rubber is made from two components, wherein the mixture ratio of the components is 0.5:1 to 0.9:1. For silicone rubber, for example, for the silicone rubber WACKER SilGel® 612 from the company Wacker-Chemie GmbH, a 1:1 mixture ratio of the components is recommended in order to achieve complete cross-linking of the silicone rubber. If this mixture ratio is changed in the specified way, a silicone rubber is obtained that has the softness required according to the invention.

Another advantageous construction of the immersion agent according to the invention is characterized in that the immersion agent has an adhesive force per area that is greater than half the material stress at failure of the elastomer, wherein advantageously it is guaranteed that the immersion agent does not detach from the coupling face of the fiber or the chip during the shrinking process.

Another advantageous construction of the immersion agent according to the invention is characterized in that the transformation point/glass-transition point T_g of the immersion agent lies below

0°C. Therefore, advantageously it is achieved that the immersion agent has the desired elastic properties over the entire operating temperature range of the coupling.

Another advantageous construction of the immersion agent according to the invention is /6
characterized in that the index of refraction of the immersion agent has a value between n = 1.3 and n = 1.7, in particular, between n = 1.4 and n = 1.5. Through this selection of the index of refraction, the coupling device is tuned optimally to the index of refraction of the fibers or the chip and the coupling attenuation is reduced accordingly.

To achieve the task named above, a device for coupling optical waveguides, for example, optical fibers or a fiber array, with an optical component/chip is characterized in that

(a) an immersion agent of the type named above is used,

(b) the distance from one end face of the optical waveguide to a coupling face of the chip equals 2-20 µm, and

(c) the volume of the immersion agent introduced to the coupling position equals less than 5 µL.

In tests it has been shown that both the properties of the immersion agent and also the spatial relationships in the region of the coupling device, that is, in particular, the distance of the optical waveguide from the coupling face of the chip and the volume of immersion agent, the quality of the coupling, and the service life of the coupling device are influenced. The formation of cracks or vacuoles can be advantageously further reduced by this arrangement if the distance of a coupling face of the optical waveguide to the coupling face of the chip lies between 2 µm and 20 µm and if the volume of the immersion agent introduced at the coupling position is less than 5 µL. If the distance between the coupling faces is less than 2 µm, then there is the risk that the coupling faces will touch or that the friction between the coupling faces will be so great that the immersion agent detaches from the coupling /7

faces. If the distance is greater than 20 μm, then the attenuation through the immersion agent increases considerably. On the other hand, by maintaining these parameters it is guaranteed that for a shrinking process, sufficient immersion agent can flow from the outside into the space between the coupling faces, so that the formation of vacuoles is avoided.

Another advantageous construction of the device according to the invention, wherein the optical waveguide fiber for coupling is arranged in a ferrule, is characterized in that the fiber is held in a ferrule and that the ferrule has, on its end face, a reduced diameter and that the coupling face of the chip is also reduced. In this way it is achieved that the distance from the edge region of the volume between the two coupling faces and the center of this region becomes smaller, so that the gel can compensate for stress occurring during the shrinking process in a better and quicker way, in order to avoid the formation of cracks and vacuoles.

Another advantageous construction of the device according to the invention is characterized in that the coupling device is surrounded by a sealing compound that has the same components as the immersion agent, but is harder, in particular, is completely cross-linked. By sealing the coupling position, mechanical impact stress and vibrations are transmitted to the coupling device only in a damped way. If the sealing compound is made from the same immersion material as the immersion material for the coupling, for example, also made from silicone rubber, an advantageous chemical compatibility of the two materials is achieved, wherein these materials differ only to the degree of hardening or in an additive of softener in the case of the immersion material at the coupling position. In /8
addition, the coefficients of expansion of the two materials are essentially the same magnitude, so that, for elongation or shrinking processes, no additional compressive or tensile forces are exerted on the immersion material at the coupling position. Finally, the sealing compound advantageously protects the elastomer immersion material from flowing out.

To achieve the task named above, a method for coupling optical waveguides, for example, optical fibers or a fiber array, with an optical chip is characterized in that

(a) an optical waveguide or ferrule connected to the optical waveguide is guided at a distance of 2-20 μm to a coupling face of the chip,

(b) an immersion material of the type named above is prepared,

(c) the immersion material is output in a quantity of approximately 5 μL to the coupling position, and

(d) the immersion material is allowed to harden according to the mixture ratio.

By maintaining the spatial relationship between the coupling face of the optical waveguide and the coupling face of the chip, that is, by selecting the distance between these coupling faces, without great effort in the coupling method it is achieved that a shrinking process or elongation process leads to a considerable formation of cracks or vacuoles also during the operation of the coupling device. The coupling method itself is as simple as in the state of the art, so that no additional effort for reducing the invention to practice is necessary. Incidentally, maintaining a larger distance between the coupling faces contradicts the previous practice, wherein attempts were made to arrange the two coupling faces as /9
close to each other as possible, in order to improve the coupling of the light beam from the optical waveguide into the chip. Surprisingly, however, this coupling becomes worse if the distance between the coupling faces is too small, because then other mechanical effects and stress effects act to the extent that the immersion material can no longer produce an adequate optical coupling between the fiber and the chip.

Another advantageous construction of the method according to the invention is characterized in that, after the hardening of the immersion material, a sealing compound is cast around the coupling position, wherein this sealing compound has the same components as the immersion material, but is harder, in

particular, is completely cross-linked. Because the same base material is used for sealing the component and also as the immersion material for the coupling, this material must be adjustable merely into different hardness values in order to be suitable for this purpose. Through the use of the same base material, not only are the advantages named above achieved, but also stock keeping is improved, because different materials do not have to be stocked for the two application purposes.

One advantageous construction of the method according to the invention is characterized in that the immersion material or the sealing compound can harden at normal operating temperature. Thus, advantageously it is avoided that the material hardens at a temperature that differs considerably from the normal operating temperature, so that stress is already exerted on the component when the component is brought from the production facility to the location where it is to be used. This stress is then added to the "normal" stress loading that occurs during operation of the component. If the original hardening of the /10
component took place at the normal operating temperature, then the formation of cracks and vacuoles is smaller also in cases when the component is located temporarily in environments at different temperatures.

Another advantageous construction of the method according to the invention is characterized in that the immersion material whose matrix contains a percentage of liquid phase is created such that a completely hardened immersion material with a softener introduced to the coupling position is processed. Through this method, advantageously already provided coupling devices can be protected against the formation of future cracks and vacuoles. In other words, by applying a suitable oil or another softener liquid on a hardened immersion material it is achieved that the immersion material is brought into a state that is suitable for the purposes according to the invention.

Another advantageous construction of the method according to the invention is characterized in that aliphatic or aromatic oils are used as the immersion oils. Also, for the subsequent conditioning of the

immersion material, these oils are suitable for the purposes of the invention, so that the desired purpose can be achieved without greater additional effort.

Embodiments of the invention will now be described with reference to the accompanying drawing in which a coupling device for coupling an optical waveguide fiber with an optical component/chip is shown schematically.

The figure shows a coupling device between an optical fiber 2 anchored in a ferrule 4 and an /11
integrated optical component, that is, a chip 6 with waveguides to be coupled (not shown). An immersion agent or immersion gel 10 is provided at the coupling position 8, wherein the volume of this agent or gel of approximately 5 μL or less fills up the intermediate space between the end face of the fiber 2 or the ferrule 4 and the coupling face on the chip 6 and also an edge region surrounding this coupling region. The parts of the coupling device are sealed in a housing 14 by a sealing compound 12.

The immersion material 10 has the following properties:

It has an index of refraction between 1.3 and 1.7, advantageously between 1.4 and 1.5.

It is a transparent elastomer with an elongation at tear greater than 300%. The elongation at tear can definitely lie at values of 1000%. For the coupling devices named above, wherein these devices permit movement between the fiber and the chip, lateral displacement between the two coupling faces of 30-40 μm occur. For a spacing of the two coupling faces of 3 μm, an elongation at tear of approximately 1000% is produced.

The immersion material has an elastic modulus below 200 N/cm^2, advantageously less than 100 N/cm^2.

The immersion material has a transformation point/glass-transition point T_g of less than 0°C.

The immersion material has the desired softness or adhesiveness such that, for example, in the case of silicone rubber, the mixture ratio of the two components is selected to be 0.5:1 to 0.9:1. Alternatively, /12

a liquid phase percentage of softener or immersion oil in a quantity of 0-10% of the quantity of the immersion material can be added, wherein the immersion liquid has a low vapor pressure.

The immersion material has an adhesive force per area relative to quartz glass of at least half the material stress at failure of the elastomer.

The layer thickness of the immersion material between the coupling faces equals between 2 µm and 20 µm, while the total length of the immersion material per fiber coupling is less than 5 µm.

The material of the sealing compound is the same base material as the immersion material, wherein the sealing compound, however, is completely hardened. The sealing compound advantageously protects the elastomer immersion material from flowing out.

Claims /13

1. Immersion agent for coupling at least one optical waveguide with an optical component, characterized in that the immersion agent is a transparent elastomer whose elongation at tear is greater than 300% and whose elastic modulus is less than 200 N/cm^2.

2. Immersion agent according to Claim 1, characterized in that the matrix of the immersion agent contains a non-cross-linked percentage of liquid phase.

3. Immersion agent according to Claim 1, characterized in that the liquid phase percentage equals 1-10% of an immersion liquid with low vapor pressure.

4. Immersion agent according to Claim 1 or 2, characterized in that the immersion liquid is an immersion oil or a softener selected as a function of the elastomers.

5. Immersion agent according to one of Claims 1-3, characterized in that the immersion agent is silicone rubber and that the immersion liquid is silicone softener, in particular, silicone oil.

6. Immersion agent according to one of Claims 1-3, characterized in that the immersion agent is epoxy acrylate and that the immersion liquid is an epoxy acrylate softener, in particular, polyisobutylene.

7. Immersion agent according to one of Claims 1-3, characterized in that the immersion agent is /14 urethane acrylate and that the immersion liquid is a urethane acrylate softener, in particular, polyisobutylene.

8. Immersion agent according to one of the preceding claims, characterized in that the softener is an aliphatic or aromatic oil.

9. Immersion agent according to Claim 4, characterized in that the silicone rubber is mixed from components, wherein the mixture ratio of components equals 0.5:1 to 0.9:1.

10. Immersion agent according to one of the preceding claims, characterized in that the immersion agent has an adhesive force per area relative to glass that is greater than half the material stress at failure of the elastomer.

11. Immersion agent according to one of the preceding claims, characterized in that the transformation point/glass-transition point T_g of the immersion agent lies below 0°C.

12. Immersion agent according to one of the preceding claims, characterized in that the index of refraction of the immersion agent equals 1.3-1.7, in particular, 1.4-1.5.

13. Device for coupling at least one optical waveguide with an optical component, characterized in /15 that

(d) an immersion agent according to one of Claims 1-12 is used,

(e) the distance (d) from one end face of the optical waveguide to a coupling face of the component equals 2-20 μm, and

(f) the volume of the immersion agent introduced at the coupling position is less than 5 μL.

14. Device according to Claim 13, wherein the optical waveguide fiber for coupling is arranged in a ferrule, characterized in that the ferrule has, on its end side, a reduced diameter and that the coupling face of the component is also reduced.

15. Device according to Claim 13 or 14, characterized in that the coupling device is surrounded by a sealing compound that has the same components as the immersion agent, but is harder, in particular, completely cross-linked.

16. Method for coupling at least one optical waveguide with an optical component characterized in that

(e) an optical waveguide or a ferrule connected to this optical waveguide is guided at a distance of 2-20 μm to a coupling face of the component,

(f) an immersion material according to one of Claims 1-12 is prepared,

(g) the immersion material is deposited in a quantity of approximately 5 µL on the coupling /16 position, and

(h) the immersion material can harden according to the mixture ratio.

17. Method according to Claim 15 or 16, characterized in that after the hardening of the immersion material, a sealing compound is poured around the coupling position, wherein this compound has the same components as the immersion material, but is harder, in particular, completely cross-linked.

18. Method according to Claim 17, characterized in that the immersion material or the sealing compound can harden at normal operating temperatures.

19. Method according to Claim 18, characterized in that the immersion material whose matrix contains a percentage of liquid phase is created in such a way that a completely hardened immersion material introduced at the coupling position is treated with a softener.

20. Method according to Claim 19, characterized in that aliphatic or aromatic oils are used as immersion oils.